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ELECTROMAGNETIC TOPOLOGICAL DESCRIPTION OF A ROCKET VEHICLE IN FLIGHT

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1009 Bradbury Drive, SE
Albuquerque, NM 87106

June 1980

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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The system topology for a rocket vehicle in flight is first developed. This system topology partitions the interaction of the system with the EMP into external interaction, intermediate internal interaction, and internal interaction. For each of the three partitions representative elementary EMP interaction problems are identified and approaches to solving some of them are discussed.

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SECTION I

INTRODUCTION

Typical elements of a multistage, long-range rocket vehicle are shown in figure 1 along with a representative electrical wire harness and external cable raceway. The external cable raceway for interconnecting the guidance and control system with the downstage components is commonly used for monocoque motor construction. The raceway cable is used by the guidance and control system to control motor ignition, thrust, vector (or other steering), stage separation, interstage jettison, and in some cases engine shutdown or thrust termination. The cable is also used to provide feedback on engine pressure, nozzle position, and perhaps other status or performance parameters to the control system. At staging, the wiring associated with the expended motor is jettisoned with the motor casing. The cable is usually provided with pullaway connectors to accommodate this operation, but mechanical and explosive cable cutters have also been used.

Smaller rocket vehicles used for ground-to-air, air-to-air, or air-to-ground missiles have similar components, but these vehicles are often one or two-stage vehicles and are usually smaller than the long-range, multistage vehicle. Smaller vehicles using forward-looking radar, infrared, or other target-seeking systems may also have the guidance and control package forward of the payload rather than aft of the payload as is usual in long-range vehicles. Finally, because the time of flight of the smaller vehicles is short, the in-flight characteristics of these vehicles are often less important than the pre-launch characteristics, insofar as interaction with the EMP is concerned. In this report, discussions are limited to the EMP effects on a long-range multistage vehicle. Other effects such as SGEMP will be neglected.

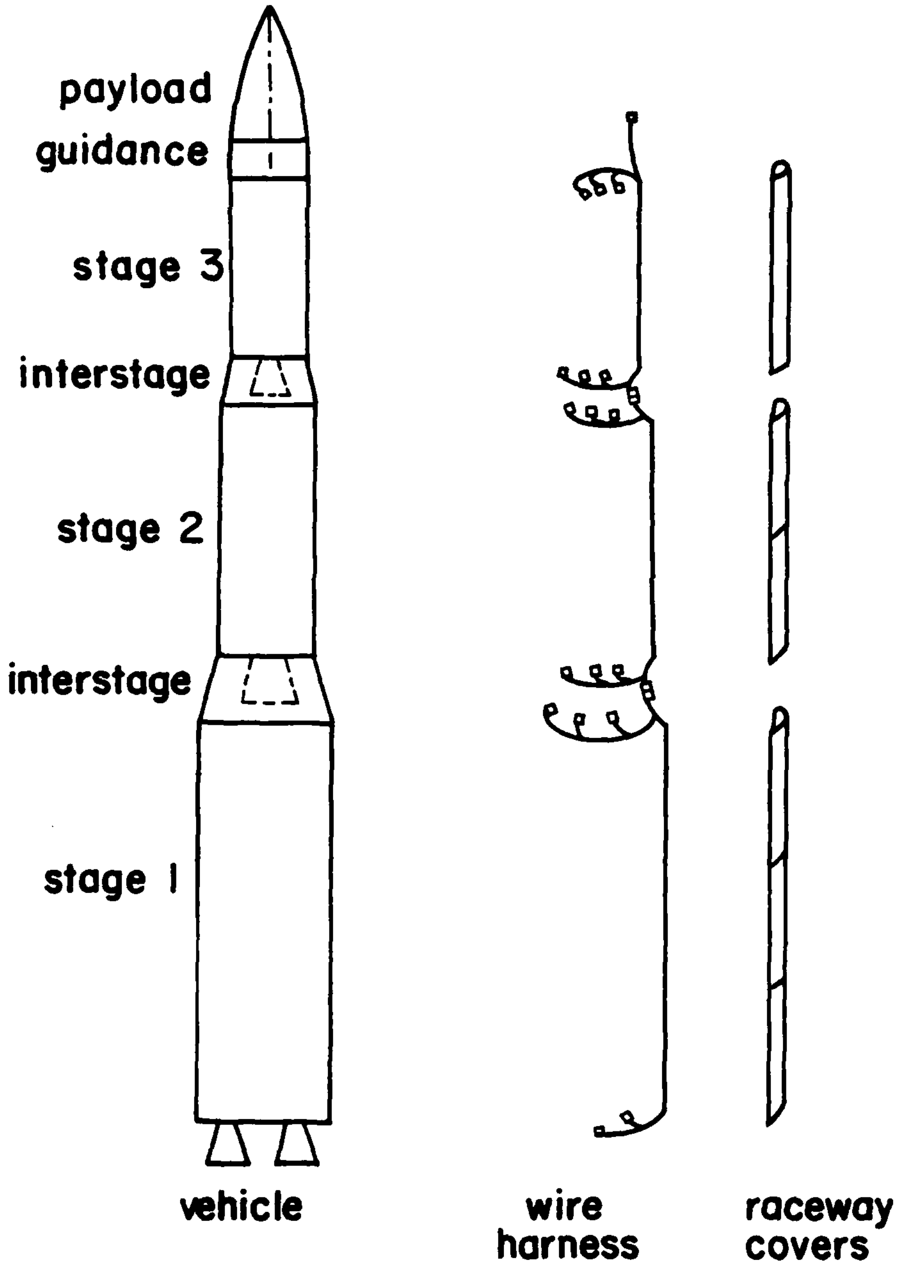


Figure 1. Multistage Rocket Vehicle, Wiring, and Cable Raceway

Representative wiring in the vicinity of the payload and guidance and control system is illustrated in figure 2. As illustrated, the raceway cable originates in the guidance and control system and branches to supply the downstage motor and staging functions. Other wiring associated with the guidance and control system may include telemetry or communication antenna cables and cabling to provide payload cover-removal, activation, and ejection. An umbilical cable is removed during launch; so the pins of the umbilical connector may be exposed to the EMP environment. Deadfacing connectors that cover, retract, or break contact with the pins may be used to reduce this exposure.

Representative wiring in an interstage area is shown in figure 3. The wiring in this region supports engine ignition and engine pressure monitoring, staging ordnance initiation, and perhaps thrust termination or motor destruction (for aborting the mission) on the downstage motor, and nozzle or thrust vector control and interstage-removal ordnance initiation for the upstage motor.

The sensitive circuits in a rocket vehicle are mainly in the guidance and control package which contains small-signal digital electronics for computing the vehicle trajectory and providing error-correction commands to the rocket steering system. These circuits are prone to EMP upset and damage. Additional sensitive circuits may be found in the steering system (near the motor nozzles) and in the staging ordnance system (electro-explosive devices).

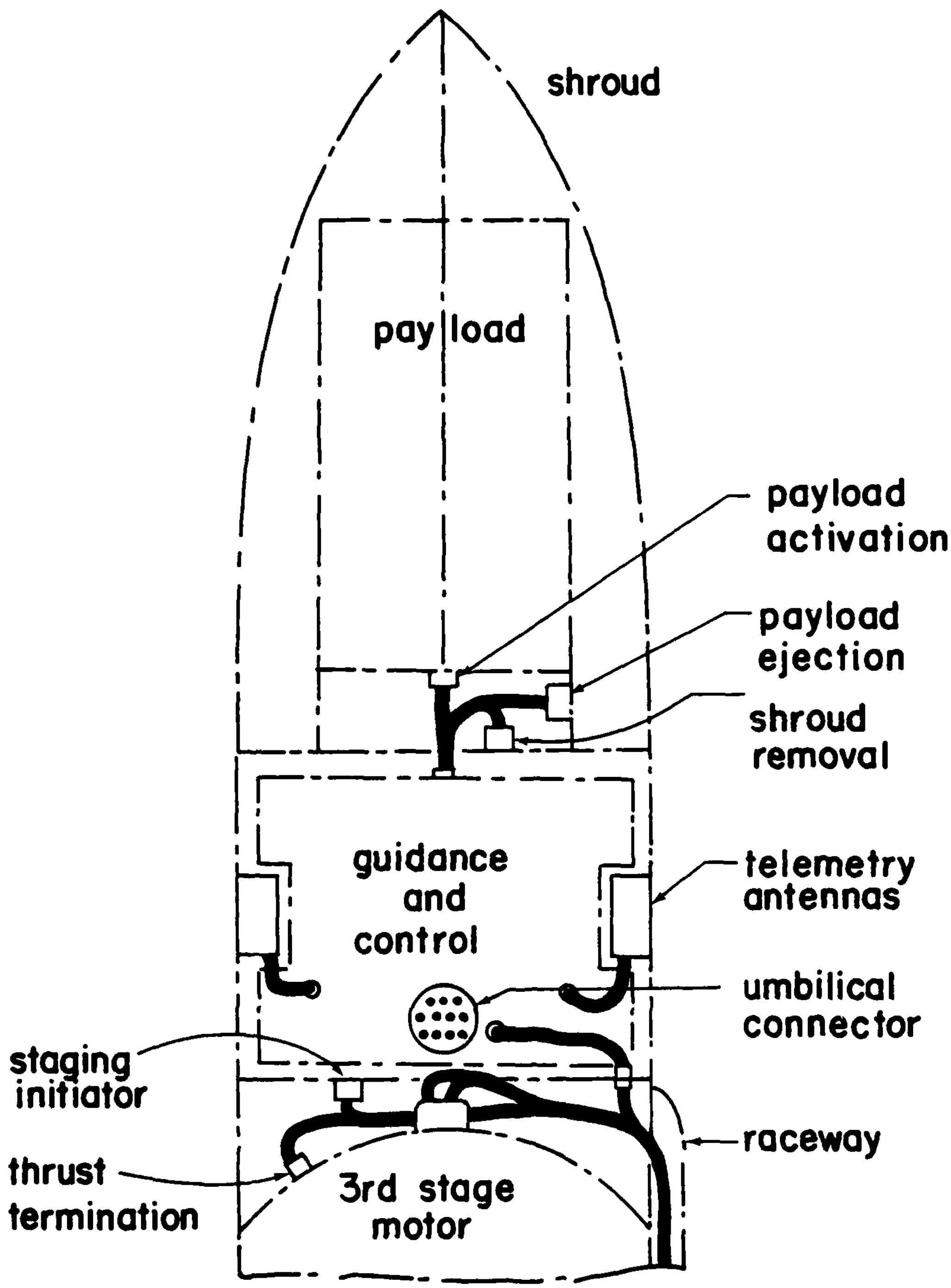


Figure 2. Typical Payload and Guidance Cabling

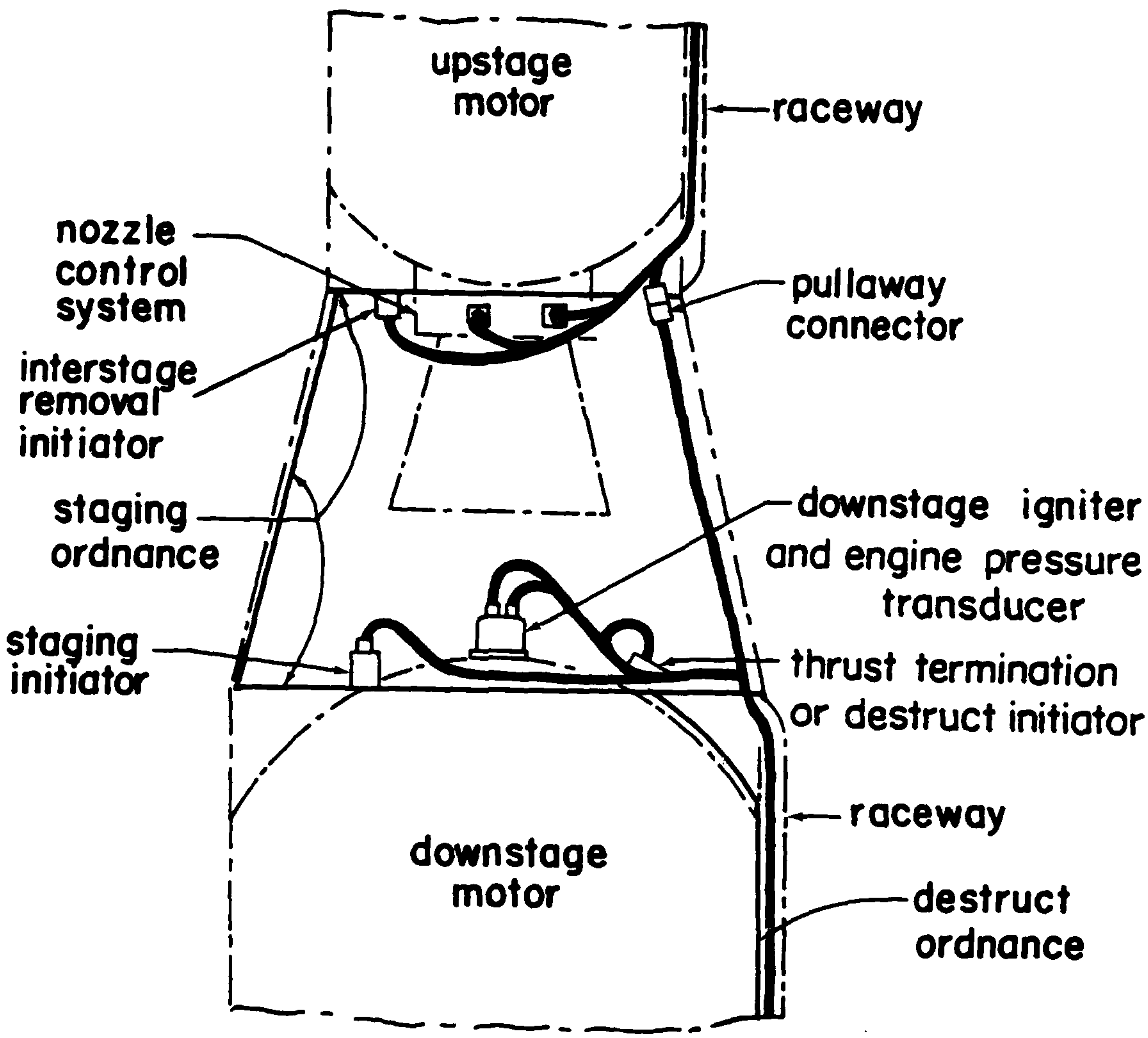


Figure 3. Typical Interstage Cabling

SECTION II

SHIELD TOPOLOGY

The primary shield for the all-metal rocket vehicle is the vehicle skin and raceway cover. Because high strength-to-weight-ratio composite materials are displacing metals for large motor casings, however, it is common for one or more of the motors (e.g., the MX missile) to be EMP transparent. As illustrated in figure 4, the primary shield is then transferred from the metal motor casing shown on the left to the raceway and interstage structure shown on the right. The current density on the raceway will usually be larger on the nonmetallic rocket than on the all-metal vehicle, and unless particular care in maintaining the shielding integrity in the interstage area and at raceway joints is exercised, the effectiveness of the primary shield on the nonmetallic vehicle may be considerable less than that of the all metal rocket.

Compromises in the primary shield often occur at joints in the vehicle skin between stages, at joints in the cable raceway covers, and at access ports on the interstage structure on the skin of the guidance and control system. The shield is also compromised at the aft end of the vehicle where the end of the raceway cable and some of its branches may be exposed. In addition, the umbilical connector and any openings for antennas on the vehicle may provide potential shield penetrations.

A portion of the second-level shield for a typical rocket vehicle is illustrated in figure 5. The second-level shield is composed of the raceway cable shield; the housings for the electro-explosive devices, transducers, and nozzle control systems; and the guidance system container. In addition, the umbilical connector may constitute an abrogation of the two-level shielding topology if conductors from this connector are connected directly to small-signal circuits inside the guidance system. Deadfacing or wire-cutting

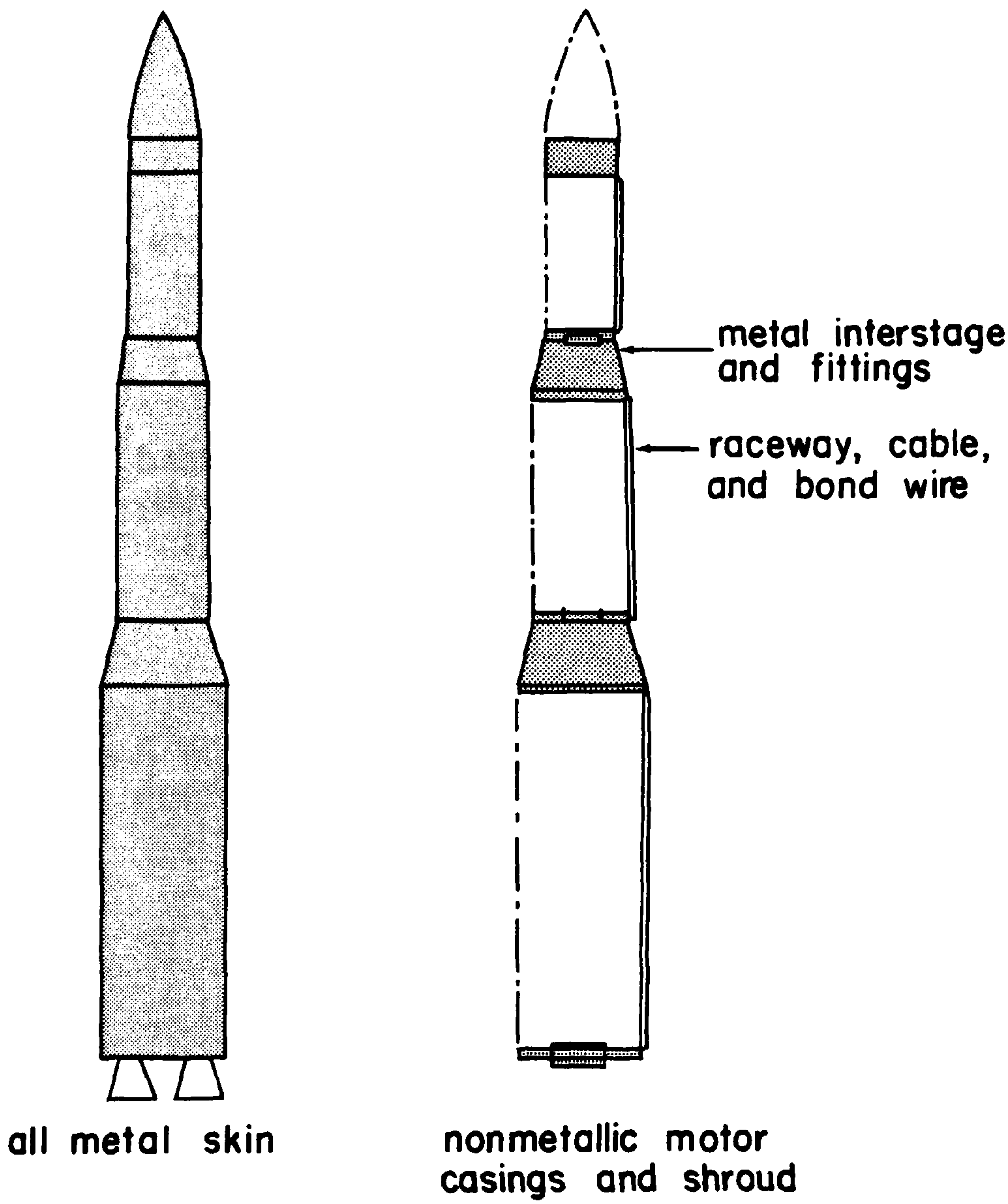


Figure 4. First-Level Shielding for Rocket Vehicles

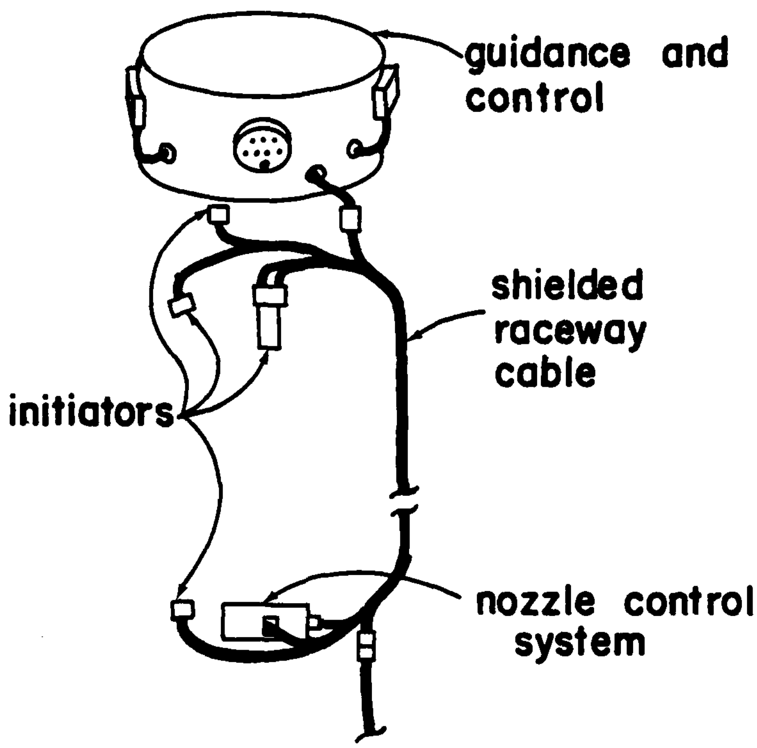


Figure 5. Second-Level Shielding for Rocket Vehicle Circuits

operations may partially restore the two-level shielding after the umbilical cable from the launch equipment is removed.

Leakage through the second-level shield may occur at connectors and along the raceway cable shield. EMP-induced interference penetrating the connector shells and cable shield can propagate along the internal conductors to the guidance and control system and to the electro-explosive initiators and nozzle control systems. EMP-induced interference can also enter the guidance and control system by means of leads from the umbilical connector and antennas.

SECTION III

EXTERNAL INTERACTION

The interaction of the all-metal rocket with the incident EMP induces surface current and charge densities and is amenable to analysis with the theory of cylindrical antennas. Because the configuration of vehicle changes as the motors are expended and jettisoned, the antenna analysis may have to be repeated for several configurations. A three-stage rocket may have 3, 4, or 5 configurations during its flight (4 if the third stage is jettisoned, 5 if the payload cover or shroud is also removed). These configuration changes primarily affect the amount of analysis required, rather than the techniques to be used. In the final configuration with the third stage and shroud removed, however, the vehicle may be more nearly characterized as a satellite than as a rocket.

A more serious complication of the analysis is encountered if the effects of the motor exhaust plume are to be determined. This complication results from the fact that the conductivity of the plume is much less than that of the metal skin and varies spatially within the plume, that the size and shape of the plume vary with altitude (see figure 6), and that the electrical properties of the plume are not thoroughly understood. Because the plume conductivity depends strongly on traces of easily ionized alkaline elements in the fuel, predictions of the conductivity based on the thermochemistry of combustion have been marginal. The attachment of the plume to the vehicle also involves complex processes in the ion sheath and boundary layer at the nozzle which are poorly understood. Nevertheless, it is believed that the plume has the effect of extending the effective length of the vehicle and causing the current density at the aft end of the vehicle to be enhanced as illustrated in figure 7.

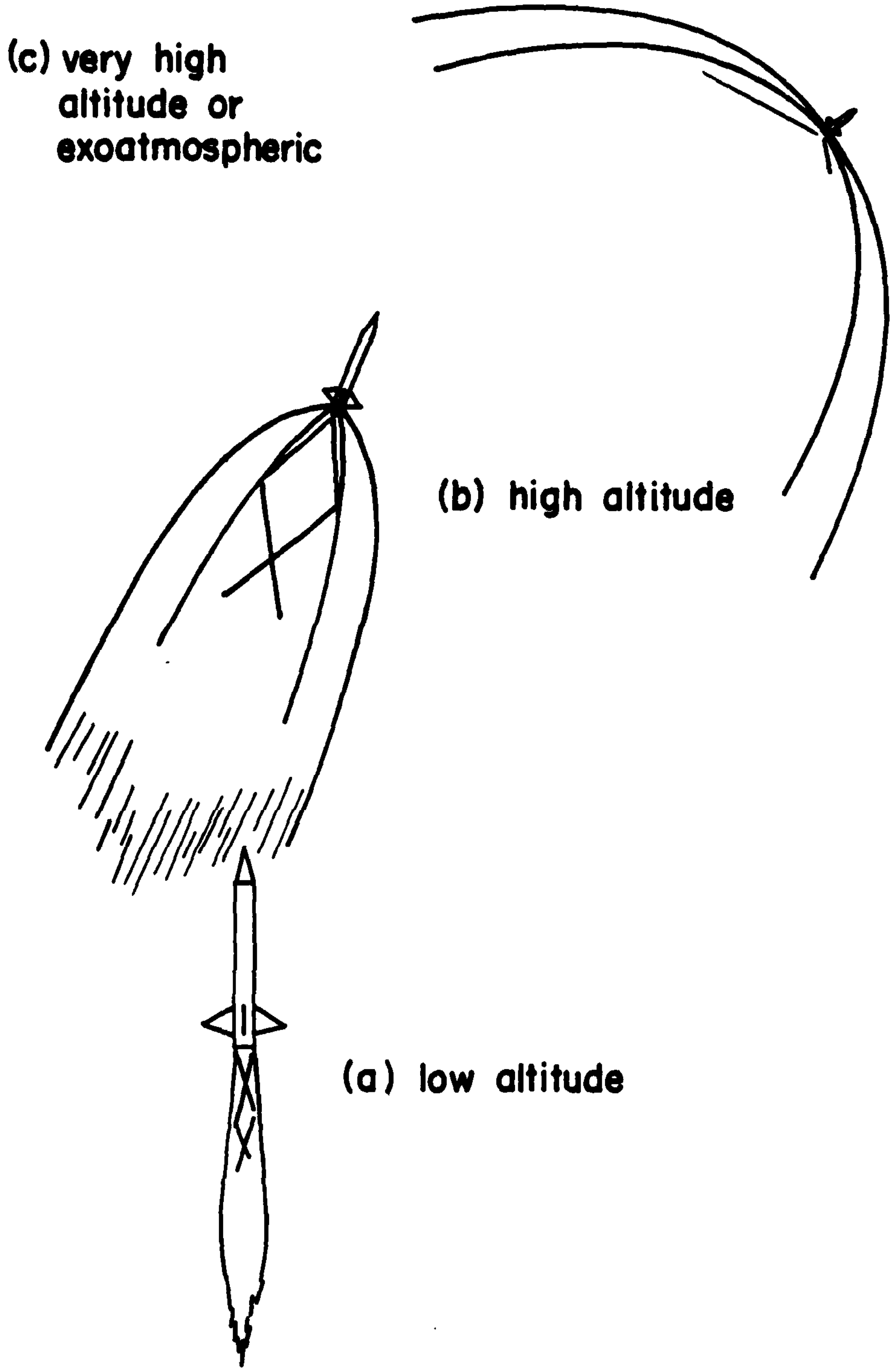


Figure 6. Rocket Motor Exhaust Plumes

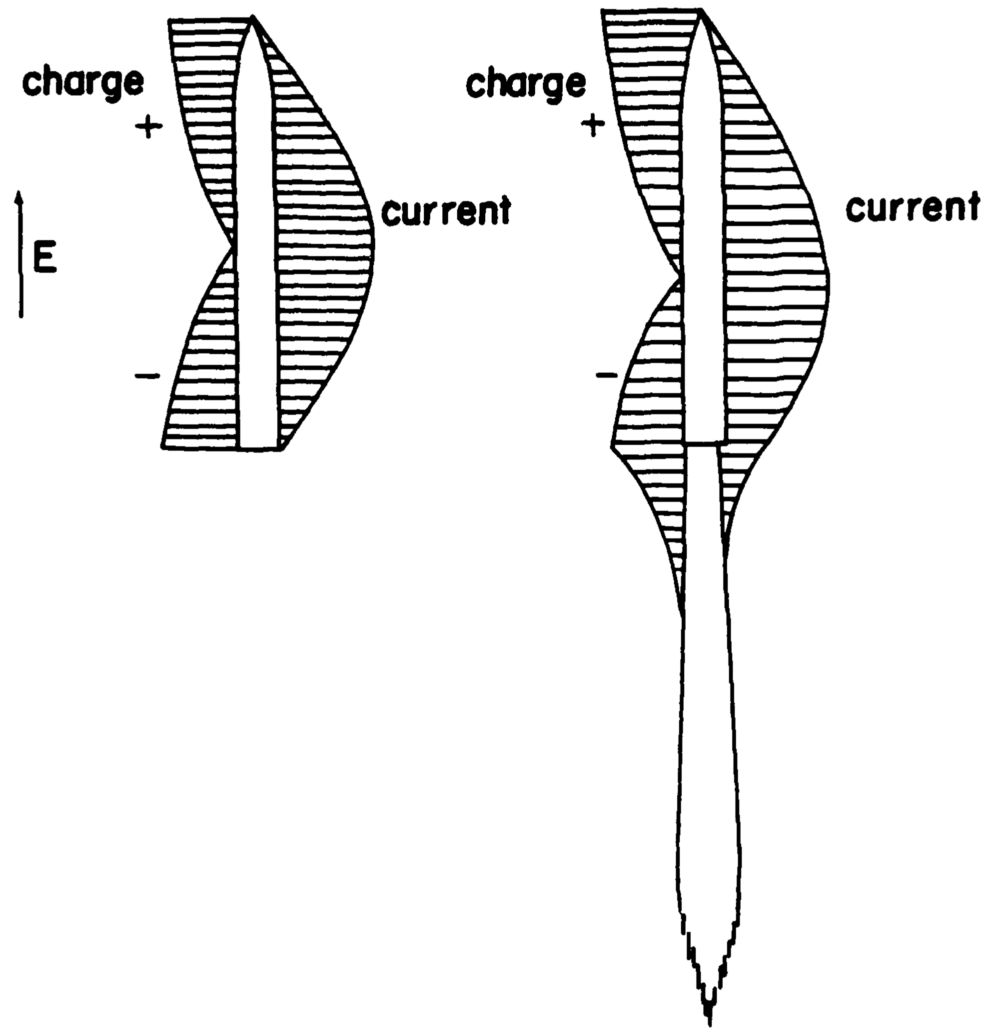


Figure 7. Quasistatic Current and Charge Distributions on Rocket With and Without Plume (Conceptual Representation)

For the rocket vehicle example, the surface charge and current densities on an all-metal vehicle (without plume) will be obtained from cylindrical antenna theory. These surface quantities, the polarizabilities of the raceway cover joints (figure 8a), and the equivalent circuit of the umbilical connector (figure 8b) will constitute the subjects of the external interaction analysis. The polarizability of the raceway cover joints may be obtained from empirical data; the umbilical circuit parameters C and h_e of figure 8b can be estimated from the theory of small antennas or obtained from empirical data.

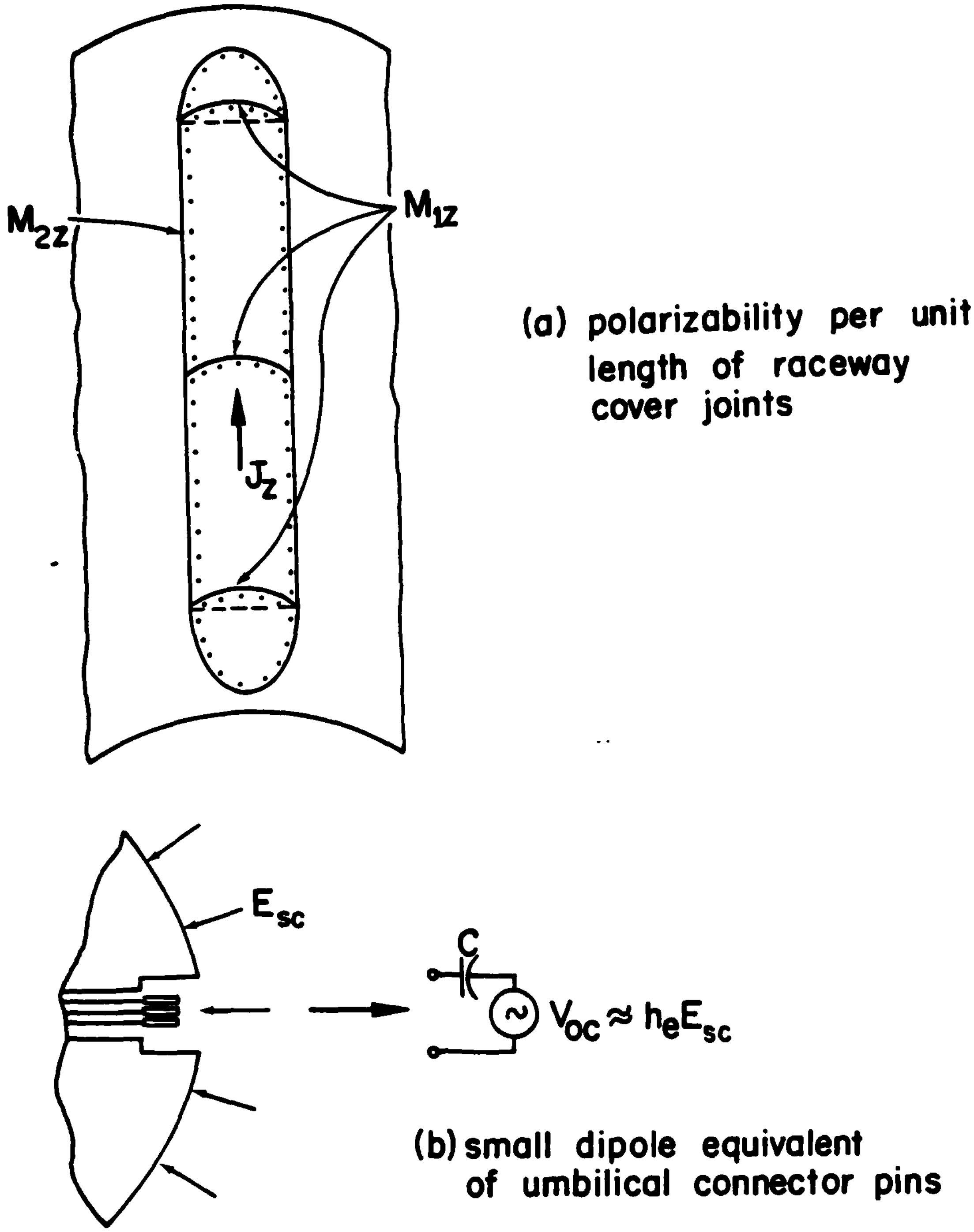


Figure 8. External Coupling Parameters for Raceway Cover and Umbilical Connector

SECTION IV

INTERMEDIATE INTERNAL INTERACTION

The intermediate internal interaction problem is to determine the current induced on the shield of the raceway cable. The analysis will treat the cable and raceway as a leaky coaxial transmission line in which the shield is the raceway and covers, and the center conductor is the raceway cable. This model is illustrated schematically in figure 9 for three vehicle configurations. The leakage through the shield is represented by a distributed longitudinal polarizability per unit length M_{2z}, representing the longitudinal raceway joints, and discrete polarizabilities $M_{1z}w$ representing the annular joints between adjacent sections of the raceway cover (w is the length of the joint; M_{1z} is the polarizability per unit length).

The joint polarizabilities and the skin current density will be used with transmission line theory to obtain the current induced on the raceway cable. Two solutions, one for the distributed longitudinal joint (figure 10a) and one for the discrete annular joints (figure 10b), will be obtained and superimposed to develop the complete solution for the current along the raceway cable. This analysis will be carried out for one of the configurations shown in figure 9 (probably the single-stage shown at the right). The cable branches in the interstage areas (see figure 1, 2, 3) will be considered electrically short so that they may be replaced by a jumped impedance for the analysis.

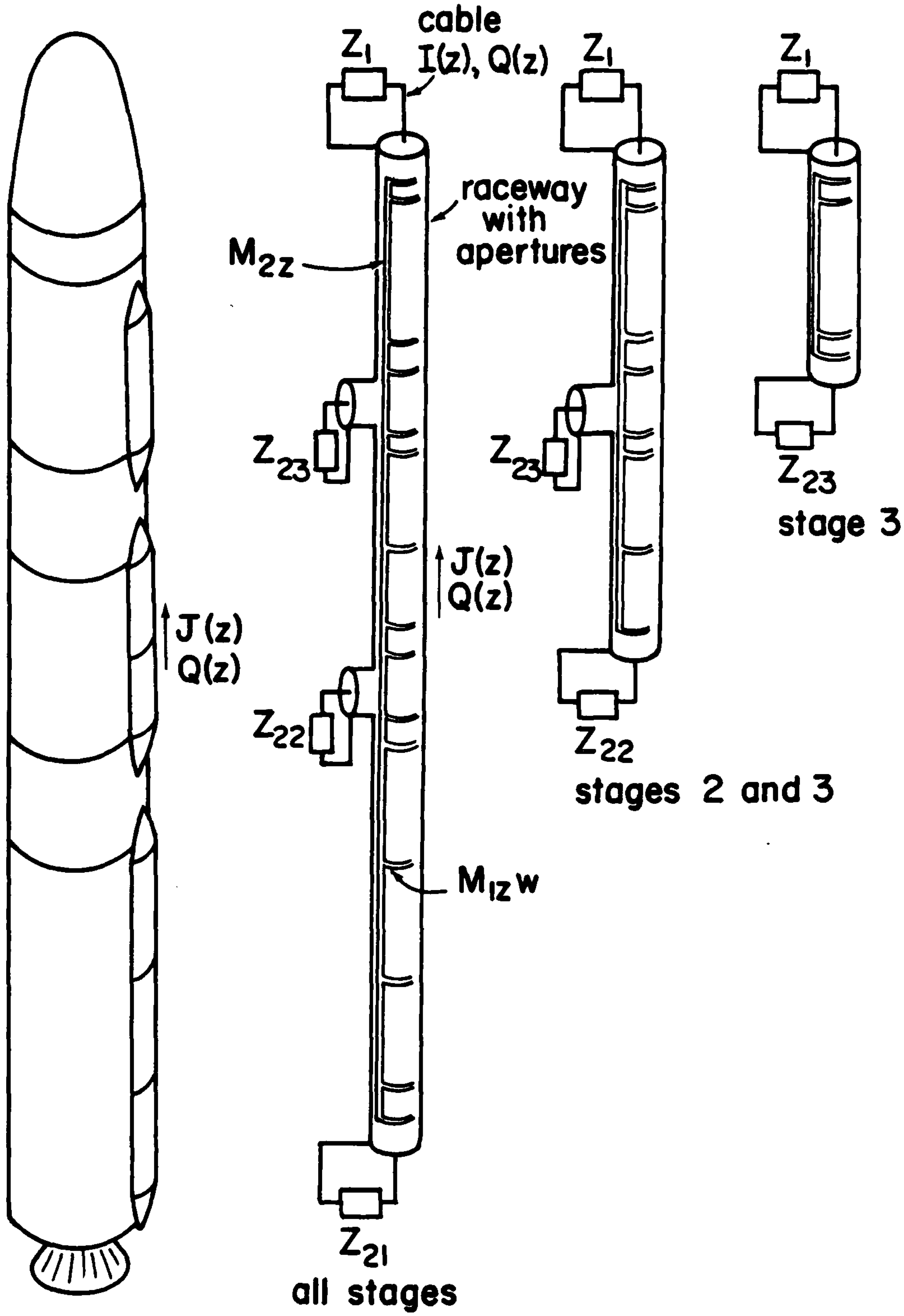
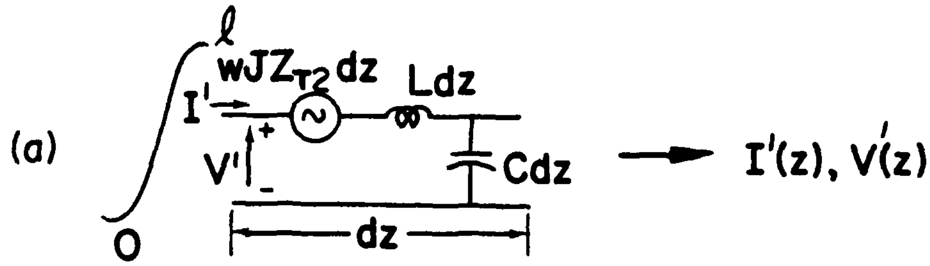
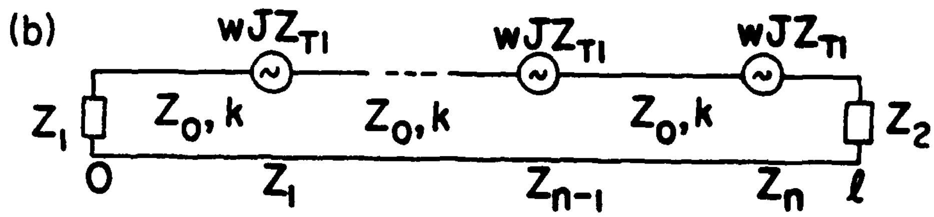


Figure 9. Excitation of Raceway Cable Through Apertures at Cover Joints



wJ = raceway cover current

Z_{T2} = transfer impedance for cover and longitudinal joint (ohms/m)



$$\sum_{1}^{n} \frac{wJZ_{T1}}{2Z_o} e^{\pm jk(z - z_i)} \rightarrow I''(z) \text{ , Etc.}$$

Z_{T1} = transfer impedance for annular joint in cover (ohms)

(c)
$$I(z) = I'(z) + I''(z)$$
$$V(z) = V'(z) + V''(z)$$

Figure 10. Determination of Raceway Cable Current From Skin Current and Cover Leakage: (a) Distributed Joint, (b) Discrete Joint, and (c) Superposition to Obtain Total Cable Current Voltage

SECTION V

INTERNAL INTERACTION

The internal interaction analysis for the rocket vehicle consists primarily of repeating the transmission line analysis using the raceway cable current and shield transfer characteristics to obtain the voltage and current of the internal conductors of the raceway cable. For the internal conductors, only the current and voltage at the cable-ends (i.e., those delivered to the sensitive components) are of interest. These quantities are induced by distributed diffusion and leakage through the cable shield (figure 11b), and by discrete leakage at the cable connectors (figure 11c). As was proposed in the intermediate internal interaction analysis, these currents and voltages can be obtained by the superposition of a distributed-source solution and a discrete-source solution. The distributed transfer impedance and transfer admittance can be derived analytically for most cable shield configurations. The discrete transfer impedance for connectors will be obtained from empirical data.

Although the raceway cable is a multiconductor cable, to simplify the analysis, it will be treated as a single-conductor cable (with shield), and only the common-mode currents and voltages delivered to lumped termination impedances Z_g and Z_i will be determined. As was done for the total cable current, the cable branches will be considered electrically short.

The current and voltage at the lumped impedances Z_g and Z_i induced by the interaction of the incident EMP with the rocket vehicle will constitute the final results for this analysis.

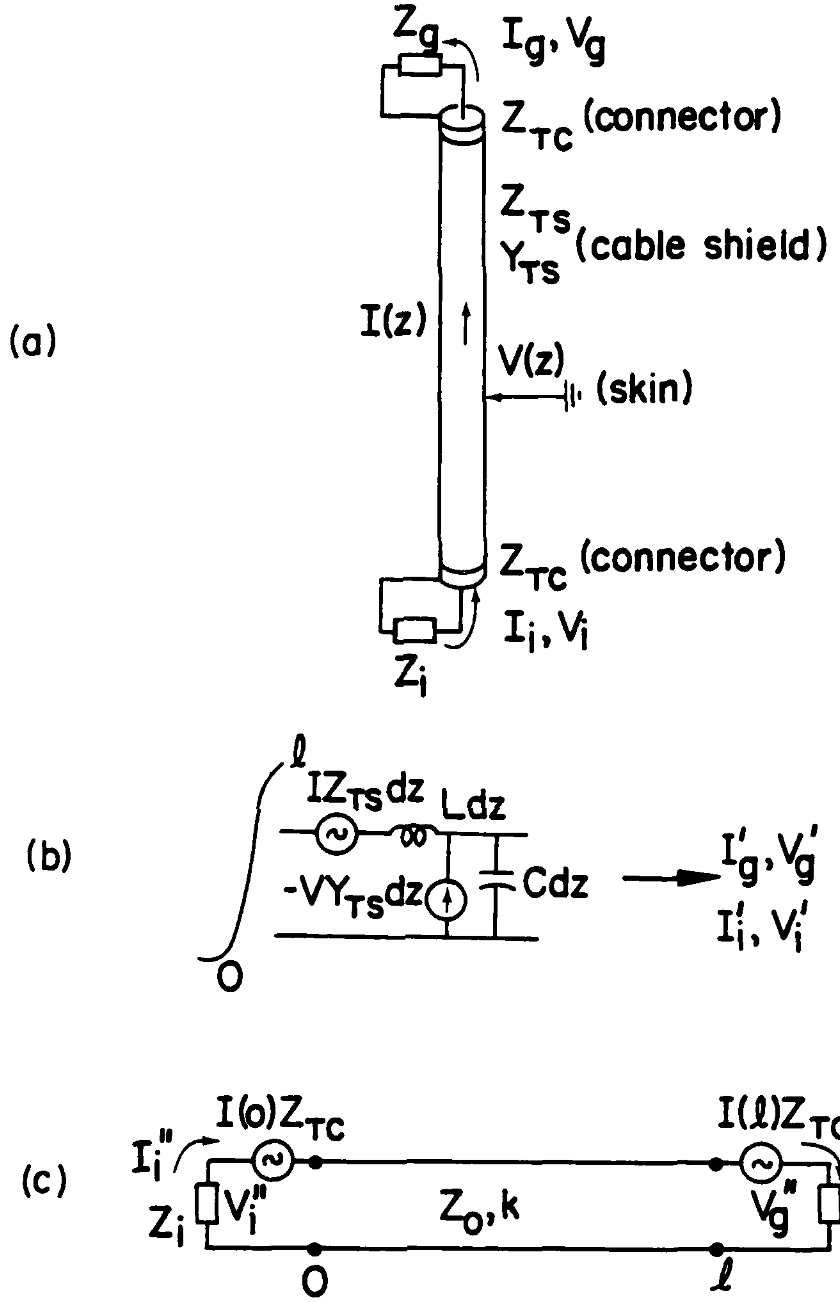


Figure 11. Voltage and Current Delivered to Loads in Guidance System and Interstage Components: (a) Shielded Raceway Cable and Connectors, (b) Voltage and Current From Distributed Coupling (Cable Shield), and (c) Voltage and Current From Discrete Coupling (Connectors)

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